Urban vegetation effects on the spatial variability of temperature in the city center

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ABSTRACT

This paper analyzes the present distribution of green spaces and roadside trees in Osaka City for mitigating the urban heat island phenomena. A classification map of natural coverage was created from 1-meter resolution aerial photographs, visible images and near-infrared images, taken in Aug. 2006. The distribution characteristics of vegetation coverage are analyzed using 3 kinds of vegetation coverage index: area ratio, the *entropy* and the *C* index. The *entropy* is an index of concentration and the *C* index is an index of continuity. The dry-bulb temperature was measured in the street using a vehicle equipped with a mobile measurement system in Aug. 2-6, 2008. The dry-bulb temperature and relative humidity in urban parks were also observed at fixed points during Aug. 2008.

Results show a relationship between temperature and continuity of vegetation coverage; the temperature is relatively lower in the street where the *C* index of vegetation coverage ratio is relatively higher.

Introduction

Our objective in this study is to evaluate urban vegetation effects on micro-climate variation. The heat island phenomena significantly affect outdoor activities in summer in Osaka city. Urban parks and roadside trees can improve the thermal environment for the urban residents. The park area per resident in Osaka City is 3.5 m^2, which is less than the average of cities in Japan, 8.1m^2. In comparison, the figure is 27m^2 in Berlin and London, and 29m^2 in New York. There are few parks, especially in the city center of Osaka, and it will be difficult to build new parks in the future. Therefore, it is important to maintain existing stocks of trees in parks or on roadsides and to increase the number of trees in the urban parks and on roadsides for the mitigation of the urban heat island phenomena. This paper surveys the current situation of vegetation coverage and temperature in Osaka City and analyzes the relationship between spatial distribution of vegetation coverage and urban air temperature.

The surface-type distribution and urban-fabric makeup of four metropolitan areas have been investigated in order to develop effective heat-island-mitigation programs (Akbari & Rose 2008). They showed that on average 29-41% of the area is covered with vegetation, 19-25% is rooftops, and 29-39% is paved surfaces. Oasis effects of vegetation canopies on urban climate have been investigated (Taha, Akbari & Rosenfeld 1991). They found that the 150x307x5-m-canopy was on the average 2K cooler during daytime than the bare and open surrounding fields. One or two rows of trees upwind of building clusters could result in savings in cooling energy.

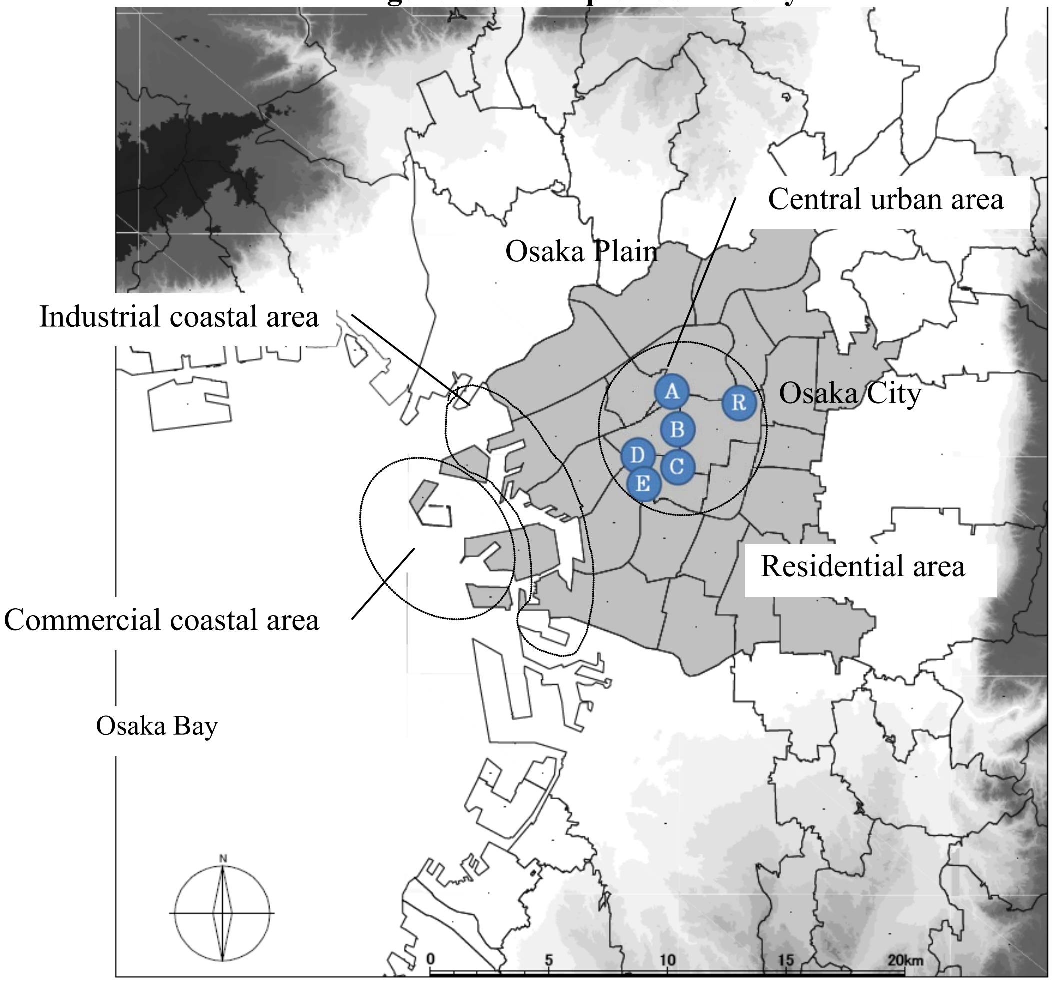
In this paper, temperature variability in an urbanized area including small parks surrounded by buildings is investigated and discussed from the viewpoint of urban vegetation coverage.

Method

Study Area

Figure 1 shows survey areas of Osaka City which is roughly divided into 4 kinds of area. Osaka City is located at the center of the Osaka Plain (from N34°48′ to N34°30′ and from E135°25′ to E135°38′). This area has developed in the downstream region of the Yodo River flowing into Osaka bay. Osaka City is the second-largest city in Japan and has a population of 2.63 million people in an area of 222km^2. There are some satellite cities in the Osaka Plain which have been wholly urbanized. This study used a classification map of natural coverage supplied by the Osaka City Government. Detail maps in Figure 2 was made using GIS (Geographical Information System) on the basis of the classification map. Survey zone A is a traditional business area, B and C are modern business areas, D and E are urban-mixed areas, and R is a redeveloped commercial area. The temperature variability was observed by measurement trips around the study area; D and E in Figure 2, in summer 2008.

Figure 1. the Map of Osaka City



The gray-shaded area shows Osaka City. Osaka City is divided into 4 kinds of area; the central urban area, residential areas, industrial coastal area and commercial coastal area. A, B, C, D, E and R show surveyed zones in detail.

Figure 2. Land Coverage of Surveyed Zones, A, B, C, D, E and R

The 500m-squares, A, B, C, D, E and R, shows the surveyed zone. Green polygons are vegetation coverage. Pink polygons are building coverage. Blue polygons are rivers. Bold dash line shows a detailed study area where temperature variability was observed. VCR means Vegetation Coverage Ratio.

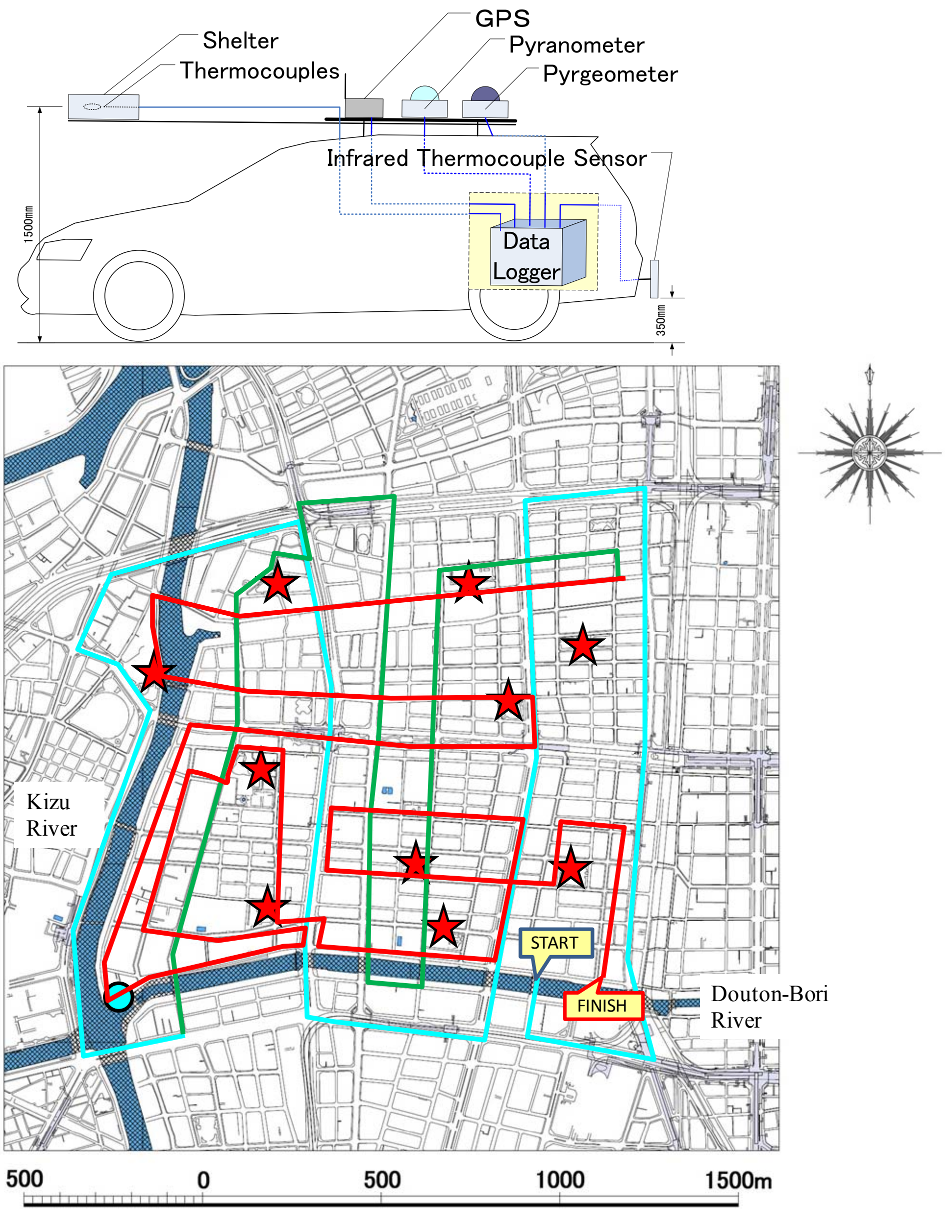
Equipment

Measurement parameters are air temperature, road surface temperature, solar radiation from the sky, long-wave radiation from the sky, UTC (Coordinated Universal Time), latitude and longitude. Table 1 and Figure 3 detail the mobile measurement system. Thermocouples are set up in a radiation shield without a ventilation device at the position of 1,500mm from the road surface. The data when running at a speed of less than 20km/h is considered to be invalid. The measurement instruments and GPS receiver are placed on the roof of the car and these data are stored in a data recorder (CR1000 by Campbell Scientific, INC.) at 1 second intervals.

Table 1. Specific of the Mobile Measurement System

Instrument	Item	Specifications
T[CC] thermocouple (0.1mmϕ)	Temperature	Temperature range:−200 to 600℃
Infrared Thermocouple Sensor (IRTS-P,CAMPBEL)	Road-surface temperature	Accuracy:±0.3℃ from −10 to 55℃
Pyranometer (MS-402,EKO INSTRUMENTS)	Solar radiation	Spectral range:300 to 2800nm,Response time:8sec(95%)
Pyrgeometer (MS-202,EKO INSTRUMENTS)	Infrared radiation	Spectral range:3 to 50μm
GPS Receiver (16-HVS,GARMIN)	latitude,longitude,UTC	NMEA(PGRMC),GPS accuracy:<15mRMS,95% typical
Data Logger (CR1000,CAMPBEL)	−	Temperature range:−25 to 50℃(operating)

Figure 2. A Cross Section Diagram of the Mobile Measurement System and the Route of Observations in the Detailed Study Area



1.5km square area was observed for temperature variability. Star marks show the fixed points observing temperature and relative humidity in urban parks. The round mark shows an automated weather station. The bold lines show the route of the observing car equipped with a mobile measurement system.

Index of Vegetation Coverage

Area ratio The classification map of natural coverage is utilized as a GIS dataset. The map was created from 1-meter resolution aerial photographs, visible images and near-infrared images taken in Aug. 2006 by the Recreation and Tourism Bureau of the Osaka City government. The natural coverage data are classified into 5 types: “grass field”, “trees or forest”, “productive green area”, “bare ground” and “water surface”. The vegetation coverage polygon data is created from groups of pixels each classified as either “grass field”, “trees or forest”, or “productive green area”. The vegetation coverage polygon data assigned as 1 of 4 classes, determined by coverage type at the center of gravity of the polygon: “roadside trees”, “plants in a private site”, “plants in parks and public spaces” and “other”. The vegetation coverage ratio is counted in each 500-meter square.

Entropy The index of concentration and distribution “*entropy*” (Kumagai et al. 2003) is also calculated in each 500-meter square.

$$entropy = \frac{1}{X_{sum}} \log \frac{X_{sum}!}{X_1! X_2! \ldots X_N!} \quad , \qquad X_{sum} = \sum_{n=1}^{N} X_n \tag{1}$$

X_N is the number of pixels of vegetation coverage in a polygon N; N is the number of polygons within the target area; X_{sum} is the total number of pixels of vegetation coverage within the target area.

C index The “*C* index” (Kobayashi et al. 2001) was suggested as an index of connectivity for the binarized-value-images. The *C* index is applied to the continuous-value-images as an index of continuity in this study. The 2D image is composed of 10-meter square meshes which has a cell value of vegetation ratio “*v”*.

$$CN_{xy} = \sum_{i=x-1}^{x+1} \sum_{j=y-1}^{y+1} v_{ij} \quad \left(0 \le v \le 1, \quad 0 \le CN \le 9\right) \tag{2}$$

CN_{xy} is a value of the cell (x,y). x is the row index of the cell, y is the column index of the cell. If v_{xy} equals 0, CN_{xy} is set to 0. CTN_{xy} is a sum total of CN in the area with width of K cells and length of L cells, with its center at the cell (x,y).

$$CTN_{xy} = \sum_{i=x-\frac{K-1}{2}}^{x+\frac{K-1}{2}} \sum_{j=y-\frac{L-1}{2}}^{y+\frac{L-1}{2}} \eta_{ij} CN_{ij} \tag{3}$$

K is the number of cells in a row and L is the number of cells in a column. Both K and L are odd-number. η_{ij} is a dummy variable. If CN_{xy} equals 0, CTN_{xy} is set to 0. For a cell (i,j) with $CN \neq 0$, η_{ij} is set to 1 if a path can be traced from that cell through adjoining cells which also have $CN \neq 0$ back to the center cell (x,y) with $CN \neq 0$. If this is not possible η_{ij} is set to 0.

$$C_{xy} = \frac{CTN_{xy}}{\sum_{i=x-\frac{K-1}{2}}^{x+\frac{K-1}{2}} \sum_{j=y-\frac{L-1}{2}}^{y+\frac{L-1}{2}} \eta_{ij}} \tag{4}$$

The center cell (x,y) has C_{xy} which is an average of CN values in the area, K times L.

Results and Discussion

Distribution of Vegetation Coverage

First, the tendency as a whole of Osaka City is analyzed. Figure 4 shows the relationship between the building coverage ratio and the vegetation coverage ratio. The vegetation coverage ratio of the central urban areas is less than 10%. Figure 5 shows the relationship between the building coverage ratio and the *entropy*. The *entropy* of the central urban areas, on the order of 3.0 - 4.0, is smaller than that of the residential areas, on the order of 3.5 - 5.0, when the building ratio is from 40% to 70%. This means that the vegetation coverage is more scattered in the residential areas. The entropy of the commercial coastal areas, which is reclaimed land, is smaller than that of the others. This means that there are comparatively large-scale green spaces.

Figure 4. Relationship between the Building Coverage Ratio and the Vegetation Coverage Ratio

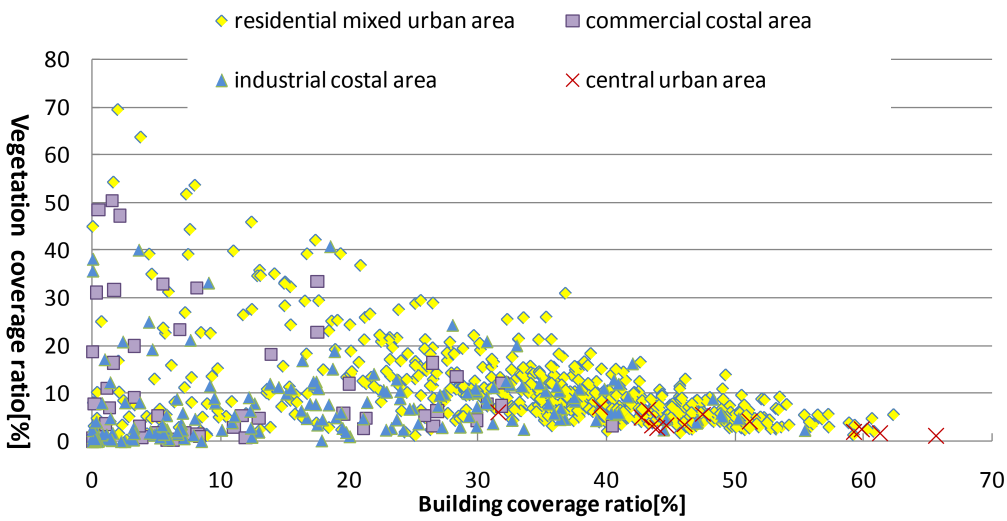
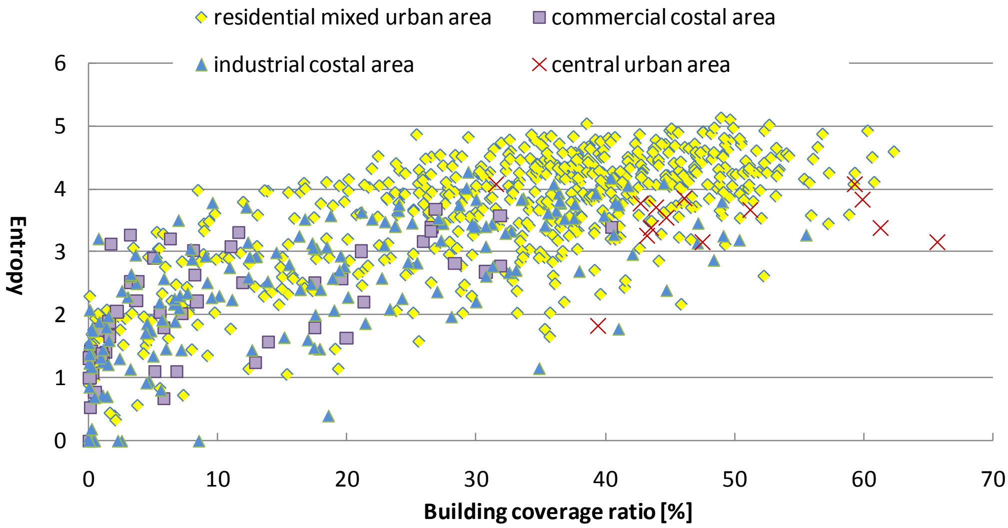


Figure 5. Relationship between the Building Coverage Ratio and the Entropy



Second, 5 kinds of zones within the central urban areas are analyzed. Figure 6 shows the land use of the surveyed zones. There is the town hall in the zone "A" which is a traditional business area. The zones "B" and "C" are modern business areas. The zones "D" and "E" are commercial areas where there are many residential buildings for downtown living. The zone "R" is a redeveloped business area.

Figure 6. Coverage Ratio of the Surveyed Zone in a 500m-square

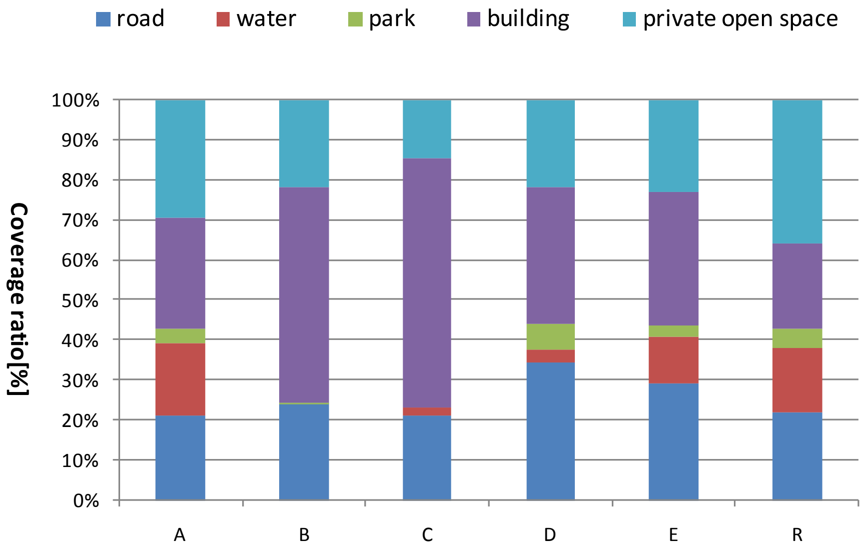
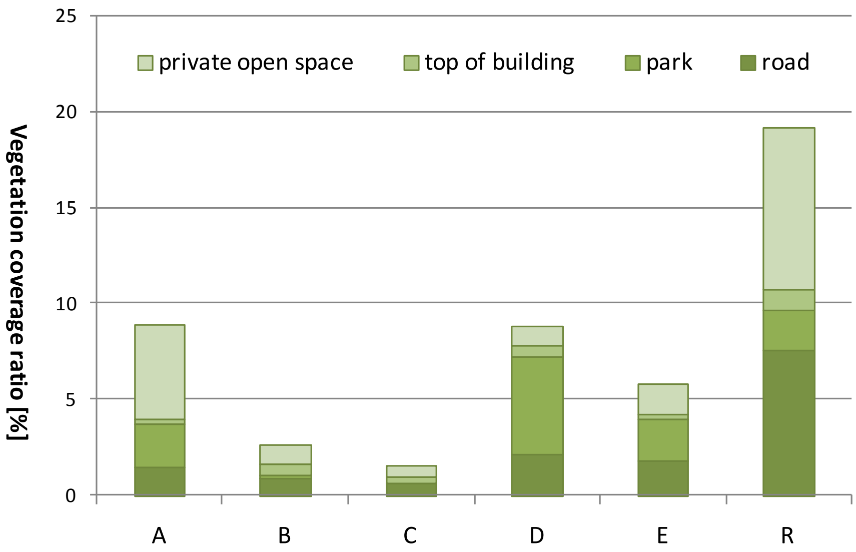


Figure 7. Vegetation Coverage Ratio and Location



The polygonal center of gravity is either on roads, in parks, on the tops of buildings or on private open spaces.

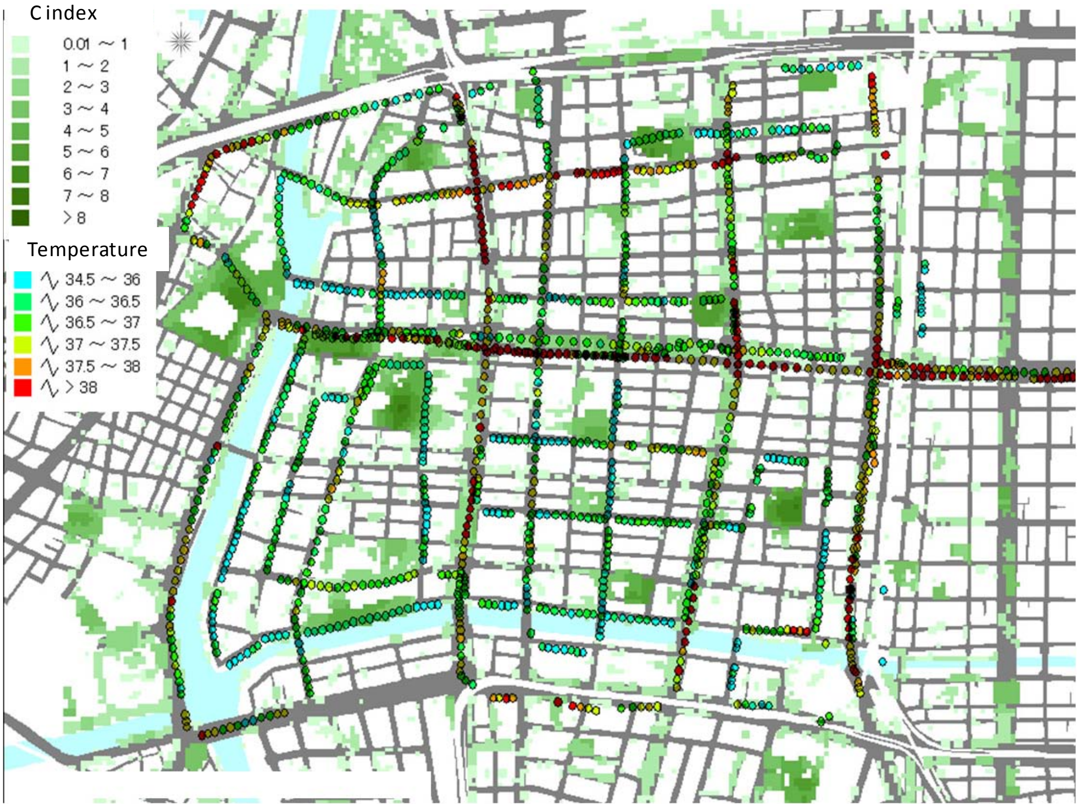
The characteristics of the green coverage are compared over the 5 kinds of urbanized areas including the redevelopment zone. As for the zone "R", the coverage ratio of buildings is smallest in the surveyed zone, on the order of 22%, and the coverage ratio of private open spaces is largest in the surveyed zone, on the order of 36%, from Figure 6. Every area's road coverage ratio is over 20%. The vegetation coverage ratio of the "R" is 19%, and that of the "B" and "C" is 1.5% - 2.5% from Figure 7. It is found that 7.5% of the redevelopment zone is covered with roadside trees and 8.4% of the zone is covered with plants on private sites. Only 0.6 - 0.8% of the "B" and "C" zones are covered with roadside trees, which is the lowest level compared with the other surveyed zones. Figure 7 shows that the vegetation coverage ratio of the zone "D" is as high as zone "A" but is characterized by vegetation in parks.

Temperature Variability

Figure 8 shows the survey area where the detailed study was carried out. It includes the "D" and "E" zones and surroundings. There are commercial buildings mixed with residential buildings and a few urban parks in this area. The *C* index of the vegetation coverage ratio is calculated on each cell, 10m square, and is shown in Figure 8. If a cell and all its adjoining cells, totaling 9 cells, have a 100% vegetation coverage ratio, that central cell is assigned the maximum *C* index of 9. In this survey area, the cells in urban parks have high score in the *C* index. The *C* index of vegetation coverage ratio has an advantage over the vegetation coverage ratio in analysis by GIS because the *C* index is useful in evaluating the continuity of cell values.

Temperature was observed on roads by the moving vehicle with the mobile measurement system, and time-based corrections were made according to the time-series data on the automated weather station in Figure 3.

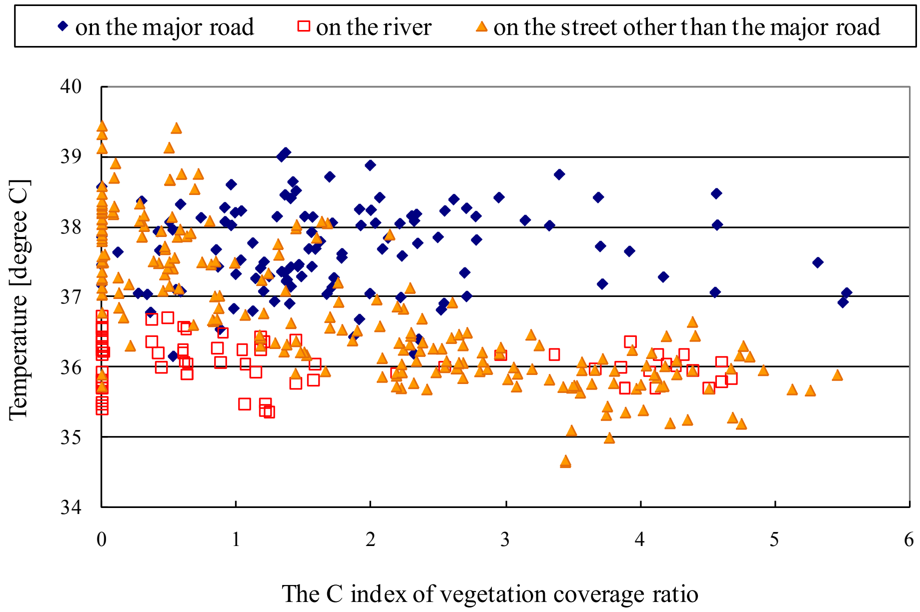
Figure 8. Temperature at 14:30 on Aug. 5, 2008 and the *C* index



Round marks show observational points of temperature. The C index of vegetation coverage ratio in the 10-m mesh is also shown by dark and light green coloring in detailed study area.

Figure 8 shows that the temperature observed on major roads with 4 or more lanes which receive much sun radiation is higher than temperature on the other streets. Figure 9 shows the relationship between the temperature and the *C* index. There is little correlation between temperature and the *C* index on the major roads. Because temperature on the major roads seem to be strongly influenced by the road surface temperature and motor vehicle emissions, the effect of vegetation has not been obvious. There is a clear correlation between temperature and the *C* index on the streets other than the major roads. When the *C* index is larger than about 2, temperature stays at a relatively low level. However, temperature on the river is relatively low regardless the *C* index.

Figure 9. Relationship between the temperature and the *C* index



Diamond marks show temperature of the points which are on the major roads. Triangle marks and hollow rectangle marks show temperature on the points which are on the streets other than the major roads. Hollow rectangle marks show temperature of the points on the river.

Conclusions

In the result of an analysis on Osaka City, the vegetation coverage ratio of the modern business zones is found to be less than 3% because of the high density of buildings, on the order of 54% - 62%. Of particular note, most roads have very low vegetation coverage in typical business zones, where there is room for increasing the number of roadside trees. The redevelopment zone has succeeded from a standpoint of increasing the vegetation coverage ratio.

The vegetation coverage ratio and the entropy as an index of concentration are found to be able to characterize 4 kinds of areas in Osaka City by the vegetation coverage.
It is found that the *C* index of the cells around the urban parks is assigned a high score, and that there is a negative correlation between the temperature on the streets other than the major roads and the *C* index. Continuity of urban vegetation coverage was confirmed to keep temperatures at a relatively low level.

The old downtowns should achieve redevelopment over the medium and long term in order to mitigate the thermal environment and air quality. As an effective first step, it is important that the sunny side of street should be covered with roadside trees which connect to the urban park as soon as possible.

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